15. Carrock Fell: a Study *in the* Variation *of* Igneous Rock-Masses.—Part II. The Carrock Fell Granophyre. Part III. The Grainsgill Greisen. By Alfred Harker, Esq., M.A., F.G.S., Fellow of St. John's College, Cambridge. (Read January 23rd, 1895.)

[Plate IV.—Map.]

Contents.

Part II. The Carrock Fell Granophyre.

9. Introduction.

In a former paper I have given a general sketch of the geology of the Carrock Fell district, and discussed the remarkable variations observed in the gabbro which is there exposed.[1] The present communication deals with the granophyre, which is closely associated with that gabbro, and with another interesting acid rock, not far distant, but belonging to a different group of intrusions.

The granophyre occurs in several distinct masses, which, from their general eye-shaped outcrop and parallelism of strike with the adjacent rocks, must be regarded as laccolitic intrusions (see sketch-map, Pl. IV.). The similarity of these neighbouring masses justifies us in considering them as a connected group. The one most easily studied is that which builds Carrock Fell itself, and extends westward in a tongue nearly as far as Round Knott. The exposures

[1] Quart. Journ. Geol. Soc. vol. l. (1894) pp. 311–335. I take this opportunity of adding a supplementary note to that paper. In describing the mineralogical constitution of the gabbro, I spoke with some caution of the occurrence of a subordinate rhombic pyroxene, inferred from the presence of certain pseudomorphs in the rock. A subsequent study of a series of slides, kindly placed at my disposal by my friend Mr. T. T. Groom, enables me to confirm this identification. One of these specimens, collected at the base of the cliff, is an unusually fresh example of the gabbro, and this contains a rhombic pyroxene in considerable abundance. Its relatively weak double refraction, pale colour, and absence of any sensible pleochroism place it under enstatite rather than hypersthene. It builds roughly idiomorphic prisms, and is often in parallel intergrowth with augite. In this case the latter mineral commonly borders the crystal, but little patches of augite are sometimes intimately associated with the enstatite with a rude micrographic arrangement. The enstatite is usually quite fresh in this slide, but in places it passes over into a greenish fibrous hornblende or actinolite [2279].

about Rae Crags, farther north-west, probably belong to a mass distinct from the preceding, separated from it by diabase, and faulted on the north against the Eycott Hill lavas and the Drygill Shales. Granophyre is seen at certain points on the moorland of which Great Lingy is the centre: if these outcrops belong to one connected mass, its extent from Roughten Gill eastward must be nearly 2 miles. There are smaller intrusions in Arm o' Grain and other gills, but we may confine our attention chiefly to the mass first indicated, which is well exposed about Carrock Fell and the Pike and in the cliffs known as the Scurth.

The question of the geological age of the granophyre and the slightly earlier gabbro is one bound up with the interpretation of the general structure of the Lake District, and must be very briefly dismissed in this place. The rocks have been intruded at the junction of the Skiddaw Slates and the Eycott Hill lavas since these two groups assumed their present mutual relations. There is reason to believe that these relations are not the natural ones, and that the absence here of certain other groups which should intervene is a result of the great post-Silurian crust-movements. If this be so, the intrusions must be later than these crust-movements. The absence of cataclastic structures or any phenomena attributable to shearing in the intrusive masses is, so far as it goes, a confirmation of this view. The faults which have displaced the intrusive rocks are to be referred to the later (post-Carboniferous) system of disturbances, with which the metalliferous lodes of the region in general seem to be connected.

10. Description of the Granophyre.

Before considering the variation exhibited by the Carrock Fell granophyre, a short description must be given of what we may regard as the normal type of the rock. It is essentially an augite-granophyre, the mineral named being always present and being the only ferro-magnesian constituent of the rock.

The only common accessory mineral is zircon, which is very generally distributed in small prisms with square cross-section. A little original magnetite occurs in a few slides, but is never prominent.

The augite of this rock presents a strong contrast to that of the gabbro. It builds crystals sometimes showing a good octagonal cross-section, more usually rather rounded and irregular, but always idiomorphic towards the felspar. The fresh crystals are of a pale to deep green tint in slices, but the mineral is commonly more or less completely replaced by a green decomposition-product of chloritic or perhaps serpentinous nature. This is strongly pleochroic, the absorption-colours changing from bluish-green to greenish-yellow: its birefringence seems to vary considerably. Uralitization is also observed in many of the slides.

The frequent association of augite with granophyric structures in our British rocks is a point worthy of passing notice. It is observed

alike in the Ordovician intrusions of North Wales and in those of Tertiary age in Scotland. In Caernarvonshire the facts are specially striking.[1] There the typical granophyres always carry augite, to the exclusion of biotite; the ruder types of granophyre and the granite-porphyries contain the two minerals together; and the true granites have biotite alone. Analyses of the Charnwood Forest rocks seem to prove that augite and micropegmatite can be formed together from magmas possessing a wide range of chemical composition.[2]

Another remark may be made on the augite of the Carrock Fell granophyres. As a rule, the length of a crystal is at most twice or thrice its breadth. In the upper part of Clints Gill, however, the most easterly tributary of Roughten Gill, the augite assumes an elongated needle-like habit. The same thing is seen east of Rae Crags, where the needles are from 1 to $1\frac{1}{2}$ inch in length and less than $\frac{1}{20}$ inch in diameter. Here, too, the idiomorphic felspar takes on a similar acicular habit. These localities are near the boundary of the granophyre, and it is interesting to compare the phenomenon with the narrow blade-like habit of the biotite in other acid intrusions in the Lake District. Mr. Marr and I have noted this feature in connexion with marginal modifications of the Shap granite[3] and the Dufton granite-porphyry.[4] It is found also in the quartz-porphyries of Potter Fell and Wansfell, and at the border of the Buttermere granophyre near Strands. The point is of interest in the present instance of the Carrock Fell granophyre; for, if the peculiar habit of the augite can be safely regarded as part of a marginal modification of the rock, it proves that the mineral crystallized after the intrusion of the magma, and indeed—since there is no parallel arrangement of the needles—after the cessation of flowing movement.

The felspars of the granophyre include scattered idiomorphic crystals and the much more abundant felspathic constituent of the micropegmatite. The former give sharply bounded rectangular sections with albite- and pericline-lamellation, and sometimes Carlsbad twinning in addition. The low extinction-angles of the lamellæ indicate oligoclase, but a frequent zonary banding, seen between crossed nicols, shows that the crystals are not quite homogeneous.

The chief bulk of the rock consists of felspar and quartz showing a great variety of 'granophyric' structures. Under this inappropriate term 'granophyric' Rosenbusch has included both evident micrographic intergrowths of felspar and quartz (micropegmatite), analogous on a small scale to 'graphic granite' (the original pegmatite of Haüy), and the various types of spherulitic and 'pseudo-spherulitic' structure. Recent researches have rendered it highly probable that the latter are merely very minute—and perhaps sometimes ultra-microscopic—groupings of felspar-fibres and intergrowths

[1] See 'The Bala Volcanic Series of Caernarvonshire,' Cambridge, 1889, § iv.
[2] Berry, Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 197.
[3] *Ibid.* vol. xlvii. (1891) pp. 277, 284.
[4] *Ibid.* p. 520.

of felspar and quartz, not essentially different from the centric type of micropegmatite. Indeed, the evidence put forward by Whitman Cross[1] and Iddings[2] amounts almost to demonstration. The Carrock Fell rock exhibits, better than any other with which I am acquainted, the various stages of gradation from a coarse and irregular micropegmatite to spherulitic intergrowths of a delicacy surpassing the resolving power of the microscope. These structures collectively will be conveniently designated 'graphic' structures. The name 'granophyre' applied to rocks of this type is perhaps too well established by usage to be abandoned.

When the intergrowth is on a relatively coarse scale, it is usually rude and irregular. Indeed, some specimens of the rock show little or no graphic structure at all, the felspar and quartz forming an irregular mosaic. In this case the quartz tends to occur partly in larger crystal-grains, and the rock approximates to some quartz-porphyries. This, however, is exceptional, almost all the slides examined showing at least a partial micrographic structure. The more finely-textured micrographic intergrowth always shows a regular arrangement. Sometimes the arrangement is linear or parallel; more frequently it is centric; but in all cases a large part of it stands in definite relation to the porphyritic crystals of oligoclase, forming a more or less regular frame round each crystal. In very many cases it can be verified that part of the felspar of the intergrowth is in crystalline continuity with the felspar-crystal which has served as the nucleus for its growth. The appearance is as if the original crystal had continued to grow throughout the final stage of consolidation of the magma, enclosing the residual excess of silica as intergrown quartz. In some instances a line of Carlsbad twinning can be traced from an oligoclase-crystal through the enveloping framework. It is clear that much of the felspar in the micrographic intergrowth must be of a plagioclase variety. In some Caernarvonshire granophyres I have found that the felspar of the micrographic intergrowth is in continuity, not with the plagioclase-crystal which forms the nucleus, but with an extremely narrow border of orthoclase investing the plagioclase.[3] In the Carrock Fell rock I have not observed this peculiarity, though it is seen in some specimens from Buttermere.

The more delicate the micrographic intergrowth, the more marked is the tendency to a 'centric' or radiate arrangement, with or without a nucleus of an earlier crystal. With increasing fineness also the sectors within which the felspar of the intergrowth extinguishes simultaneously become narrower, until they are represented between crossed nicols merely by dark rays when their direction makes a small angle with one of the cross-wires. The felspar of the intergrowth takes on more markedly the form of radiating fibres, and seems to make up a larger proportion of the whole. This latter appearance is perhaps illusory, but it is certain that the aspect of

[1] Bull. Phil. Soc. Washington, vol. xi. (1891) pp. 411–444.
[2] *Ibid.* pp. 445–464.
[3] 'The Bala Volcanic Series of Caernarvonshire,' 1889, p. 48.

these radiate aggregates is determined chiefly by the minute radially-grouped fibres of felspar which obscure the associated quartz.

From the micrographic the transition is unbroken to what may be called the 'cryptographic' structure, in which the individual elements of the intergrowth are no longer to be distinguished, Here presumably the constituent sectors are still more attenuated, and the radial arrangement of the fibres is in consequence more perfect. A black cross is seen between crossed nicols, though, owing to the slightly oblique extinction of the felspar which is the dominant mineral-element, the arms of the cross are not very perfect nor accurately at right angles. The structure is thus the pseudo-spherulitic rather than the truly spherulitic of Rosenbusch, but from our point of view the distinction is not essential.

Graphic intergrowths are not always restricted in this rock to the quartz and felspars: exceptionally they affect the other constituents also. Certain slides show a radiate grouping of the minerals on rather a large scale (relatively to the field of the microscope), imperfect prisms of felspar being arranged like the spokes of a wheel. In this case the green augite occurs in irregular rod-like and elongated patches sharing the general radiate disposition [2280]. Again, there are not wanting indications of a micrographic intergrowth on a small scale between augite and the other constituents, including magnetite, though the decomposition of the augite renders the appearance rather obscure. So far as I have observed, this structure is found only in the remarkable basic modification of the granophyre near its junction with the gabbro.

The following analysis of the Carrock Fell rock is due to my friend Mr. George Barrow, F.G.S., of the Geological Survey of Scotland. It may be taken as representing the composition of an average specimen; the specific gravity was found to be 2·670 :—

	III.
SiO_2	71·60
Al_2O_3	13·60
Fe_2O_3	2·40
MgO	0·21
CaO	2·30
Na_2O	5·55
K_2O	3·53
Loss on ignition	0·70
	99·89

III. Granophyre, 100 yards east of summit, Carrock Fell. The iron is estimated as ferric oxide, but doubtless occurs mostly in the lower form: the figure given corresponds to 2·16 of ferrous oxide.

The analysis by Mr. J. Hughes given in Mr. Ward's paper[1] shows a general agreement with the above, except as regards the soda, which must be largely overestimated.[2]

[1] Quart. Journ. Geol. Soc. vol. xxxii. (1876) p. 24.

[2] It is evident that, when the only alkali-bearing minerals are felspars, the molecular ratio $K_2O+Na_2O:Al_2O_3$ in the bulk-analysis of a rock cannot be greater than unity, and must be less if a lime-bearing felspar or an aluminous pyroxene be present. The ratio calculated from Hughes's figures is 1·7 : 1.

From Mr. Barrow's analysis, in conjunction with the microscopical examination, the mineralogical composition of the granophyre may be calculated as follows:—

	Plagioclase.	Orthoclase.	Quartz.	Augite.	Totals.
SiO_2	32·90	13·50	20·96	4·24	71·60
Al_2O_3	9·75	3·84	...	...	13·59
FeO	...	...	...	2·15	2·15
MgO	...	...	...	0·21	0·21
CaO	0·33	...	...	1·97	2·30
Na_2O	5·55	...	...	...	5·55
K_2O	...	3·53	...	...	3·53
	48·53	20·87	20·96	8·57	98·93

From this it would appear that the plagioclase-felspar of the rock is one of the albite-oligoclase series with a ratio Ab : An = 7·4 : 1, or nearly 15 : 2, its percentage composition being as below. This, however, is only the average composition, and it may well be that the porphyritic crystals are of a more typical oligoclase, while the triclinic felspar which, with the orthoclase, makes the felspathic constituent of the micrographic groundmass is a more nearly pure albite.

Plagioclase.	
SiO_2	67·79
Al_2O_3	20·09
CaO	0·68
Na_2O	11·44
	100·00

Augite.	
SiO_2	49·47
FeO	25·09
MgO	2·45
CaO	22·99
	100·00

The augite would appear to be a diopside approaching hedenbergite, the ratio Mg : Fe being 21 : 215, or nearly 1 : 10; but the calculation is probably of little value in view of the small part which the mineral plays in the rock. It is evident, however, that the augite cannot be of a variety rich in alumina, and this makes another point of contrast with the augite of the gabbro.

11. Variation observed in the Granophyre.

Over a large part of its extent the granophyre of the Carrock Fell intrusion does not seem to vary much from the specimen analysed, and the same is true of the intrusions of Rae Crags and Great Lingy. The highest percentage of silica found was 77·38, at a spot below the Scurth, about 500 yards W.N.W. of Stone Ends farm.[1] On the other hand, portions of the Carrock Fell mass are

[1] The following silica-percentages of different specimens of granophyre I owe to the gentlemen named in my former paper. Those marked S were determined at Sidney Sussex College by Messrs. Brend and Cunningham-Craig, those marked L were determined at Leeds by the pupils of Dr. Cohen:—

(i) Below Scurth, at 500 yards W.N.W. of Stone Ends:
Silica 77·38 (S); sp. gr. 2·607.
(ii) In peat-moss S. of Drygill Head: Silica 75·3 (L); sp. gr. 2·530.
(iii) Outcrops 100 yards E. of Carrock Fell summit:
Silica 71·60 (Barrow); sp. gr. 2·670.

considerably less acid than what has been described as the normal type. The specific gravity increases from 2·7 to 2·8 and even to 2·9 or more. This is at the southern margin of the intrusion, where the silica-percentage of the granophyre, in contact with the gabbro, has fallen to less than 60. The microscope shows that concurrently the rock becomes richer in augite, and in its most basic phase contains a notable proportion of iron ores and apatite, with sometimes a little biotite.

These variations are sufficiently apparent in hand-specimens taken in the field. The normal type of granophyre shows small scattered crystals of black augite and white or glassy-looking oligoclase, in a fine-textured grey, or cream-coloured, or reddish groundmass. In some of the more acid examples the augite is wholly or almost wholly absent, and the rock has a white colour. This is the case at the head of Brandy Gill and in the peat-moss south of Drygill Head, and the specific gravity of these specimens is naturally very low (2·578 and 2·530). In other places the granophyre becomes richer in augite, the lustrous columnar crystals of that mineral and the duller black spots which mark its decomposition-products, together with the white crystals of felspar, being more closely set in the reddish or brownish granophyric matrix. This variety prevails especially towards the southern boundary of the Carrock Fell intrusion. The augite is not only more abundant, but in larger crystals, and indeed the whole rock assumes a coarser aspect in this part of the mass. On the actual margin these peculiarities are more marked, and are worthy of more detailed notice.

Before describing the special phenomena at the junction of the granophyre with the gabbro, however, it will be convenient to enquire whether the facts already broadly stated lead to any plausible explanation of the variation observed in the different parts of the acid intrusion. The occurrence of the densest and most basic type of granophyre on the southern edge of the mass, which seems to represent its base as originally intruded,[1] suggests at once the differentiating action of gravity. There are two ways in which this might conceivably take effect: namely, by a stratified arrangement of layers of different density in a magma still wholly fluid, or by the sinking of crystals already separated out in the magma.

The former hypothesis, which is as old as Durocher's famous theory, has been made the basis of speculations by several writers, and I have endeavoured to develop it in connexion with the suc-

---

(iv) Carrock Fell summit: Silica 69·044 (Hughes, *cit.* Ward); sp. gr. of specimen from same locality, 2·657.

(v) Close to junction with gabbro, lower part of Furthergill Sike: Silica 60·0 (L); sp. gr. 2·805.

(vi) Another specimen from the same place: Silica 58·26 (S).

I have made specific-gravity determinations on specimens from twenty other localities, and found them a useful check upon the examination of hand-specimens and slices. The figures are all corrected to the standard temperature, 4° C.

[1] See my former paper, Quart. Journ. Geol. Soc. vol. l. (1894), section on p. 314.

cession of the Ordovician lavas and the associated intrusive rocks in Caernarvonshire.[1] It may have an application also to a system of sills or laccolites of cognate origin, such as those belonging to the earlier (probably Ordovician) system of intrusions in the Lake District.[2] In such cases we are dealing with differences of level of many thousands of feet, and it is doubtful whether differentiation of this kind could produce appreciable effects within the limits of a single body of eruptive rock such as can be exposed for our examination. Even if the parallel between a rock-magma and a saline solution be granted, physical researches on solutions do not give us any quantitative results available for our purpose. In simple solutions Gouy and Chapéron[3] have calculated that the concentration by gravity would become sensible only in a vertical column at least 100 metres in height. On the whole, we cannot at present look to this process as likely to have been an important cause of differentiation in a laccolite of moderate dimensions, such as the Carrock Fell granophyre. Moreover, there are facts for which it offers no explanation.

The idea of minerals separated out in the early stages of crystallization sinking to the bottom of an otherwise fluid magma is also one that has been entertained by other writers, and I have elsewhere applied it to some of the later (post-Silurian) intrusions on the border of the Lake District.[4] It does not seem, however, to afford an explanation of the facts in the present case. In the intrusion of Carrock Fell itself the basic modification of the granophyre is certainly found along the southern, *i. e.* the lower, boundary; but if we consider the other granophyre-intrusions in the neighbourhood, already enumerated, we see that no such rule holds good. We cannot then ascribe the richness in augite, iron

[1] 'The Bala Volcanic Series of Caernarvonshire,' Cambridge, 1889, § viii.

[2] The following are arranged in descending order :—

(i) Sill of quartz-porphyry between Ashgill Shales and Coniston Limestone, Far Old Park, Dalton-in-Furness; sp. gr. 2·574.

(ii) Sill of microgranite in Coniston Limestone, Taith's Gill Bridge, near Sedbergh; sp. gr. 2·590.

(iii) Sill of quartz-porphyry in banded ashes near Long Crag, Wrynose Gill; sp. gr. 2·597.

(iv) Sill below banded ash-group on west flank of Helvellyn; sp. gr. 2·726.

(v) Irregular sill of dolerite near junction of Volcanic Series with Skiddaw Slates, Lyulph's Tower, Ullswater; sp. gr. 2·803.

(vi) Irregular sill or laccolite of hornblende-picrite (of Mr. Postlethwaite) in Skiddaw Slates, Great Cockup; sp. gr. 2·923.

There seems to be no exception in the Lake District to the rule that the lower sills are of denser rocks than the higher. The figures stated are, of course, for the solid rocks, but it is safe to assume that those for the fluid magmas would give the same relative order.

The vertical range here represented must be very considerable; Mr. Clifton Ward estimated the thickness of the Volcanic Series alone at 12,000 feet.

[3] 'Sur la Concentration des Dissolutions par la Pesanteur,' Ann. Chim. et Phys. ser. 6, vol. xii. (1887) pp. 384–393. Actual experiments on this point by Bischof and others have not yielded any consistent results.

[4] 'The Lamprophyres of the North of England,' Geol. Mag. 1892, pp. 199–206; 'Porphyritic Quartz in Basic Igneous Rocks,' *ibid.* pp. 485–488.

ores, and apatite of certain parts of the granophyre to the effect of gravity, whether operating on the fluid magma or on minerals crystallized out at an early stage.

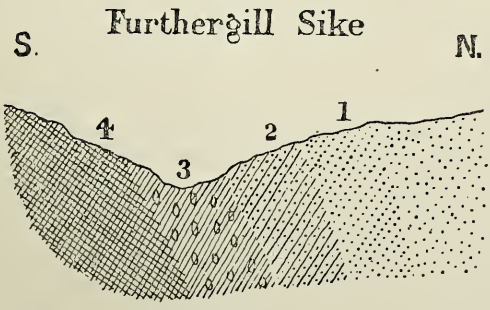
As already remarked, the tracts occupied by granophyre are often covered by peat-mosses and other superficial accumulations, and the precise limits of the intrusions are in some places a matter of conjecture; but all that can be observed favours the view that the basic modification of the rock is a marginal phenomenon, and comes in near the contact of the granophyre with the gabbro. The gabbro-intrusion we know to be of somewhat earlier date than that of the acid rock, but it is highly probable that the interval between the two was a short one, so that the acid magma was intruded among rocks already hot. We should not, therefore, look for a marginal concentration of the earlier products of crystallization in the granophyre, such as we have found evidence of in the gabbro; and the phenomena here considered must be different in kind from those discussed in my former paper. In proof of this it must be remarked that the basic margin to the granophyre is found (so far as our knowledge goes) only where that rock is in contact with the gabbro. For example, the granophyre about Rac Crags and to the south, which is in contact with the later intrusion of diabase, is of a thoroughly acid type (specific gravity 2·647).

These considerations suggest that the curious modification of the Carrock Fell granophyre on its southern border is due to a reaction between the acid magma and the highly basic margin of the previously consolidated but still hot gabbro. It will be seen that this idea is confirmed by a closer examination of the rocks in question.

12. Junction of the Granophyre with the Gabbro.

The junction of the granophyre with the gabbro is best observed in Furthergill. The following section is seen in a distance of 3 or 4 yards from north to south, low down in the little sike, just before

Fig. 1.



the outcrops are lost under the alluvial fan. No. 1 is granophyre of specific gravity 2·705, and doubtless of considerably less acid

composition than the normal type. From this it differs mineralogically, chiefly in the greater abundance of augite which it contains. That mineral builds the usual idiomorphic crystals, but is largely replaced by green hornblende and other substances. We also note the presence of iron ores, which were mentioned as rare, and apatite, which was almost wholly wanting, in the normal type. The idiomorphic zoned felspar-crystals are abundant, and the interstitial micropegmatite occupies somewhat less space than formerly. No. 2 has a specific gravity of 2·805, with a silica-percentage of only 58 or 60. The augite, in rather large idiomorphic crystals, is somewhat more abundant, and the apatite and iron ores are also more prominent constituents. In addition a little biotite is found. Besides the beautiful micropegmatite which clings about the idiomorphic felspars, there is in places what looks like a kind of micrographic arrangement in the destroyed augite and even in the iron ores. The same thing is seen in No. 3, a still more basic rock, of specific gravity 2·925. The augite and its alteration-products are perhaps a little more plentiful, and the same may be said of the iron ores, the apatite-prisms, and the scanty flakes of biotite. The idiomorphic felspars are often seemingly untwinned, but their zonary banding is still marked. The micropegmatite is reduced in quantity, and tends to consist mainly of quartz. On the other hand, there are micrographic intergrowths of felspar and (destroyed) augite. This rock has a very compact, dark aspect in the field, and weathers into spheroids. It seems to represent the actual border of the granophyre-intrusion, for it is in contact with undoubted gabbro, though of somewhat peculiar character. Some brecciation indicates a certain amount of crushing along the line of junction, but there is evidently no break of importance. The gabbro, No. 4, is the extreme basic modification of that rock, its specific gravity being 3·200 and its silica-percentage only 33·4. It exhibits the peculiar metamorphic effects noted in my former paper, such as the abundant production of tremolite, sphene, etc., with the destruction of the original minerals; but enough remains of the latter to mark the fundamental difference between this rock and the preceding. For instance, the augite of the gabbro is of the pale greyish-brown variety with characteristic basal striation, and always moulds the felspar-crystals.

In this section we see that, notwithstanding the curious basic modification of the granophyre towards its southern margin, the line of separation between that rock and the gabbro can be drawn with absolute sharpness. The fact that the gabbro becomes progressively more basic towards its northern boundary has already shown us that there is no passage from the one rock to the other in the usual understanding of the words; we now see that neither chemically nor mineralogically is there a gradual transition from the one intrusion to the other. The silica-percentage of the granophyre, for instance, decreases gradually down to about 58, but then the figure drops *abruptly* to $33\frac{1}{2}$ in the ultrabasic gabbro. Again, the granophyre becomes continually richer in augite as we approach

the Furthergill stream, yet there gives place to a rock containing abundant augite indeed, but of a quite different variety, namely, the aluminous ophitic augite with basal lamellation which we have found to characterize the gabbro-mass throughout its extent.

Following the line of junction up Furthergill Sike and westward towards Round Knott, we do not always find quite identical relations. Though the abrupt break is not bridged over, there are places where the difference in silica-percentage between the two rocks in contact one with the other would probably be less than that just noted. This is where there has been a certain impregnation of the marginal gabbro by granophyre.[1] So far as my observation goes, this is exceptional, and does not extend more than a couple of feet from the actual junction. The anomalous character of these quartz-bearing ultrabasic rocks is very striking. One, with a specific gravity of 3·026 to 3·122, is seen in the prominent crag overlooking Furthergill Sike at the spot marked by the letter F on the 6-inch Ordnance map.

In some places, too, the relations are complicated by apophyses of the granophyre traversing the gabbro. This complication is brought out by a longer traverse across Furthergill Sike, a little above the crag just mentioned. It is not necessary to give full details of this section. The basic modification of the granophyre (α, sp. gr. 2·724) is in contact with the highly basic iron-ore-gabbros (β, sp. gr. 3·060, and δ, sp. gr. 3·190), but the latter are divided by a tongue of thoroughly acid rock (γ, sp. gr. 2·636).

On the fell above there are only occasional exposures along the line of junction. About 100 yards south of the Carrock Fell sheep-fold is seen a very coarse rock containing columnar black crystals up to 2 inches in length. These are, in the main, of hornblende, but it is not clear to what extent that mineral is derivative from augite. Certainly in some cases, in this and other specimens, hornblende occurs with its own proper crystal-forms. Biotite, iron ores, and apatite are also seen in a hand-specimen, while the microscope shows a micrographic groundmass clinging round the large idiomorphic felspars. Augite occurs also both in idiomorphic crystals, with partial uralitization, and in micrographic intergrowth. This rock, with a specific gravity of 2·738, is not unlike No. 2 of the above section, though perhaps a little more acid.

About 300 yards west of the summit of Carrock Fell occurs another coarse-textured rock which, on a large scale, shows a curious mottling of pink felspathic and black pyroxenic patches. The idiomorphic felspars here tend to narrow elongated forms. Biotite is present, as well as the abundant augite and hornblende. This rock has a specific gravity of 2·904, and corresponds to No. 3 of the section noted above. This and the preceding evidently belong to the basic margin of the granophyre. The dark ultrabasic gabbro, metamorphosed and partially impregnated with granophyre, is seen in loose blocks, but does not make any show *in situ*. This is

[1] See my former paper, Quart. Journ. Geol. Soc. vol. l. (1894) pl. xvii. fig. 6.

explained by its tendency to weathering; as seen in Furthergill it is usually very rotten. Dark brown mica, magnetite, and needles of apatite are conspicuous among the partly decomposed augite, hornblende, etc., of the crumbling rock.

All these facts are consistent with, and seem to lead to, the conclusion that portions of the highly basic gabbro have become incorporated with the acid magma near the junction of the two intrusions. The manner in which the actual margin of the gabbro as now seen is locally impregnated with granophyre proves that such an absorption of gabbro-material into the acid magma must have taken place to some extent, the mode of occurrence of the veins and nests of micropegmatite in the iron-ore-gabbro pointing clearly to corrosive action rather than merely mechanical disruption. The absorption in this way of some constituents of the gabbro must, on the edge of the solid mass, have disengaged crystals of other constituents, to be floated off in the acid magma and, whether fused or not, to modify the composition of the resulting rock. If we may suppose such an action to have taken place to any considerable extent, the peculiarities observed in the marginal part of the granophyre find a sufficiently simple explanation. That considerable portions have been removed from some parts of the gabbro-margin we have seen independent reasons for believing. (See p. 331 of my former paper, Quart. Journ. Geol. Soc. vol. l. 1894, and the accompanying map, pl. xvi.)

If such a reaction as that postulated on the above grounds, between the already consolidated basic gabbro and the acid magma, be admitted as a possibility, it may throw some light on the nature of the process to enquire what has become of the several constituents of the destroyed gabbro. The order of formation of minerals from a rock-magma does not in general correspond exactly with the (reversed) order of fusibility of those minerals, and many geologists have preferred the analogy of the crystallization of a mixture of salts from solution. Conversely, the absorption of crystallized minerals by a fluid magma may be compared with solution or chemical corrosion rather than with dry fusion. Since, however, the order of consolidation of the constituents of our gabbro is the same as their (reversed) order of fusibility, this question need not be discussed. The augite of the gabbro, then, would be the mineral most readily attacked, and it seems to have been wholly dissolved and its substance incorporated in the granophyre-magma; no augite resembling it is found in the basic margin of the granophyre-intrusion. From its interstitial mode of occurrence in the gabbro it is clear that the removal of the augite from the marginal part of that rock would set free the crystals of the other constituents. The felspar seems also to have been dissolved in great part, though it is possible that some of the relatively large crystals of plagioclase seen in the modified granophyre have been directly derived from the older rock. These crystals are much more plentiful here than in the normal

granophyre, and they frequently show a clear border surrounding a turbid nucleus of rounded shape and corroded appearance. Of such a derived origin there seems to be clearer indication in the case of the less fusible minerals, the iron ores and apatite. The shape of some of the larger opaque grains in such rocks as Nos. 2 and 3, described above, is significant. Especially may be remarked skeletons or frameworks, apparently of ilmenite, which perhaps represent the intergrowths of ilmenite and magnetite in the gabbro from which the latter mineral has been dissolved out. The apatite-crystals in the basic modification of the granophyre exactly resemble those in the gabbro, and are probably derived, without alteration, from that source. It will be remembered that this mineral is foreign to the normal granophyre.

The 'caustic' action of a fluid magma upon solid rocks has been studied by many geologists in connexion with the phenomena of enclosed fragments, and an excellent summary of knowledge on this point has recently been given by Zirkel.[1] From this it appears that in extreme cases an enclosed fragment of an igneous rock may be completely dissolved, with the exception of a few refractory minerals such as zircon, sapphire, etc. The corrosive action is most intense when the rock attacked and the absorbing magma differ widely in acidity; and we thus see why the action of the granophyre-magma upon the highly basic gabbro was much more energetic than that of the gabbro-magma upon the enclosed masses of basic lava (compare my former paper). A high temperature is another factor involved; and probably the peculiarity of the conditions in the present case lay in the intrusion of a considerable body of highly heated acid magma into contact with an extremely basic rock which had not had time to cool. It is in accord with this idea that we find no phenomena like those under discussion in the smaller granophyre-intrusions of the district, including the dykes and veins, which are of uniformly acid character. We have already seen evidence that the granophyre-magma was intruded before the beginning of crystallization in it, and therefore in a highly heated condition. On the other hand, it is probable that its temperature was not very much higher than the minimum thus implied, for the fact that the dissolved basic material was not diffused through the whole magma, but remained near the margin, seems to indicate a certain degree of viscosity.

The only instance that I have found, of an unusually dense and presumably basic variety of the granophyre in the interior of the mass, is in the face of the Scurth opposite the 'Apronful of Stones' marked on the 6-inch map. The specific gravity here was found to be 2·814. This may possibly be due to the absorption of an enclosed portion of Eycott lava. Near the same spot I collected specimens which seemed in the field to represent such an inclusion in a highly altered condition, but, if this be their true nature, the metamorphism is too great to admit of any confident identification.

[1] 'Lehrbuch der Petrographie,' 2nd ed. vol. i. (1893) pp. 593–602.

Without much success I have examined the accounts of several foreign areas for phenomena corresponding with those seen at Carrock Fell. The Lake Superior region at once suggested itself as one in which both gabbros and acid rocks are largely developed, the latter being apparently as a rule posterior in date to the former. The varied groups of gabbros, which there occupy large tracts of country and have been described by several American geologists, offer some curious points of resemblance to the Carrock Fell gabbros. Among these features may be mentioned the wide variations met with in the group as a whole, the local variations marked by differences in the relative proportions of the several constituent minerals, the banded or quasi-stratified arrangement of different types in some localities, the existence of ultrabasic modifications extraordinarily rich in titaniferous iron ores, and the presence in other varieties of orthoclase and micropegmatite. The acid rocks, described under such names as augite-syenite, soda-granite, quartz-keratophyre, 'red rock,' etc., are characterized sometimes by biotite, sometimes by augite. Structurally a large number of them seem to be granophyres, and to agree very closely with Lake District examples.

At one locality, Pigeon Point in Minnesota, Mr. W. S. Bayley has described some remarkable features at the junction of an olivine-gabbro with a granophyre ('quartz-keratophyre').[1] Between the two there occurs a zone of rocks chemically intermediate between them and becoming progressively more basic from the side of the granophyre to that of the gabbro. From his examination the author regarded 'the intermediate rock as due to the fusion and re-crystallization of the materials of both the [granophyre] and the gabbro, in consequence of the irruption of one of these rocks into the other at some considerable depth below the surface of the earth, where the conditions were such as to produce a rock with the characteristics of a plutonic rock.' Subsequently he modified this view, and came to the conclusion that the granophyre 'is a product of contact-action between the gabbro and the bedded rocks,' and has arisen from the fusion of the latter (slates and quartzites).[2] The field-evidence on which this change of opinion is based seems to be by no means convincing, and I venture to think that the author's earlier conclusion is not seriously shaken. It may be remarked that, whatever the interpretation of the facts may be, Pigeon Point is probably not the only place where such relations will be found. Bayley points out that the red rocks which R. D. Irving styled augite-syenites, etc., are in part like the normal granophyre of Pigeon Point, in part like the intermediate types there observed, and those of the latter division 'are always, so far as could be determined, in close association with gabbro.' Some of the rocks figured by Irving[3] closely resemble slides in my collection from the basic margin of the Carrock Fell granophyre, though not its most basic part.

[1] Amer. Journ. Sci. ser. 3, vol. xxxvii. (1889) pp. 54–63.
[2] *Ibid.* vol. xxxix. (1890) pp. 273–280.
[3] 'The Copper-bearing Rocks of Lake Superior,' Monogr. U.S. Geol. Surv. vol. v. (1883). See especially pls. xiv., xv.

Mr. Bayley has kindly sent me a few specimens of the Pigeon Point rocks for comparison with my own. So far as can be judged from these, the relations may well be the same in the two districts. The red rock is a granophyre differing from that of Carrock Fell in having biotite instead of augite, and in containing idiomorphic crystals of quartz as well as of plagioclase. In one slide the micrographic intergrowth which makes up the bulk of the rock is on a very minute scale, and passes into what I have styled the cryptographic structure. The 'intermediate' rocks, as in the Carrock Fell district, are somewhat coarse in texture. They are granophyres, in that they have a groundmass of felspar and quartz with micrographic arrangement, but in other respects they differ from the 'red rock.' Iron ores and apatite have come in rather abundantly, and biotite is now only subordinate, the dominant ferro-magnesian mineral in the slides examined being an augite with basal lamellation and 'herring-bone' structure.

[Prof. Sollas has worked out very thoroughly the modification of a granophyre-magma by the absorption of basic material in the case of the numerous dykes which traverse the gabbro of Barnavave, Carlingford.[1] The action of the acid magma upon the derived crystals is much more clearly exhibited there than in the rocks which I have studied. The relations between the earlier gabbro and the later granophyre are evidently different in the two areas. At Barnavave the gabbro appears to have been traversed by contraction-joints and fractured by earth-movements before the injection of the granophyre; and, in consequence of this and of a miarolitic structure in the gabbro, the acid magma was able to penetrate the basic rock in an extraordinarily intimate manner. Prof. Sollas gives reasons for believing that the 'granophyric gabbro' of Barnavave has been produced from ordinary gabbro by this process of impregnation, and suggests that the same explanation may apply to Carrock Fell. According to my observations, however, such action does not there extend to more than a foot or two from the well-defined line of junction with the main body of granophyre, while the quartz-gabbro constituting the central part of the basic intrusion gives evidence of an entirely different origin.—March 2nd, 1895.]

Part III. The Grainsgill Greisen.

13. Description of the Greisen and its Relation to the Granite.

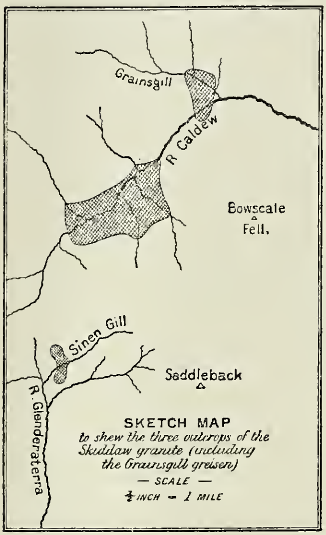
The quartz-mica rock which is here styled 'greisen' is, as already intimated, a peculiar modification of the Skiddaw granite, and the simple course in describing it will be to treat it at once from this point of view.

The well-known Skiddaw granite is seen in three isolated but neighbouring exposures, each at the bottom of a valley and with the appearance of underlying the surrounding slates with a quasi-

[1] 'On the Volcanic District of Carlingford and Slieve Gullion:—Part I. On the Relation of the Granite to the Gabbro of Barnavave, Carlingford,' Trans. Roy. Irish Acad. vol. xxx. (1894) pp. 477–512.

horizontal surface of junction. This feature and the general similarity of the several outcrops make it probable, as surmised by Ward, that the three are parts of a single mass, which must then extend from S.S.W. to N.N.E. for a distance of at least 4 miles. The most southerly exposure is in Sinen Gill, a tributary of the Glenderaterra, on the west side of Saddleback; the next and most extensive is in the Caldew valley, near Wiley Gill and Burdell Gill; the third, with which we are more immediately concerned, is lower down the same valley, near the junction of Grainsgill with the river Caldew. Ward's fourth area, consisting of 'poorly developed' or 'bastard granite,' at the head of Brandy Gill, I find to be an intrusion of granophyre which has no connexion with the Skiddaw granites.

Fig. 2.



The rock of the first and second exposures calls for no special remark. It is essentially a biotite-granite, consisting of orthoclase, oligoclase, quartz, and brown mica. The last encloses numerous little zircons, each surrounded by its characteristic halo of intense pleochroism, which is very conspicuous even when the mica is much decomposed. It must be remarked, however, that, in addition to the magnesian mica, there are often scattered flakes of muscovite, which are always subordinate and not constant enough to be regarded as an essential constituent. The quartz is in part enclosed by the felspar or, in places, roughly intergrown with it.

Coming now to the third area of granite, and beginning with its southern portion, as seen in the bed of the river, we notice a certain difference. The rock is somewhat more acid, yielding 77·26 per cent. of silica as compared with 75·223,[1] and its specific gravity has diminished from 2·624 to 2·604. With this we find that white

[1] In addition to the other gentlemen named above, I am indebted to Mr. A. Harden, of Owens College, Manchester, who has superintended the determination of several silica-percentages in his laboratory. One of these is indicated by the letter M in the following list:—

(i) Granite, White Gill: Silica 75·223 (Hughes).
(ii) Granite, bed of Caldew, 300 yards above junction with Grainsgill Beck: Silica 77·26 (S); sp. gr. 2·604.
(iii) Greisen, near foot of Brandy Gill: Silica 78·13 (M); sp. gr. 2·646, another specimen 2·669.
(iv) Greisen, eastern slope of Combe Height, 250 yards south of Grainsgill Lead-mine: Silica 80·36 (Spencer); sp. gr. 2·684.
(v) Greisen, small inlier in Grainsgill Beck, 400 yards above junction with Brandy Gill: Sp. gr. 2·682.

mica has become an essential constituent, occurring frequently in parallel intergrowth with the brown. Besides this mica, clearly original, there are in places many minute scales developed in the interior of the felspar-crystals in a manner suggestive of secondary change. Part of the quartz is enclosed by orthoclase, or tends to form with it a rude graphic intergrowth.

In the road, less than 100 yards farther north, the white mica is seen to be somewhat more abundant, but the rock is too much decomposed for examination. Going northward up the hill which occupies the angle between Grainsgill and the Caldew, we see no more exposures for nearly 100 yards, during which the character of the rock has completely changed. Biotite has disappeared, and the rock is seen to be composed essentially of quartz and white mica. The microscopo shows that a little orthoclase still occurs, though in very subordinato quantity. Much of the mica is not strictly colourless in sections, but has a yellowish tinge with faint pleochroism. The mineral occurs in two ways: firstly, as flakes of some size, but of rather irregular contour and often moulding the quartz and felspar; and secondly, as densely packed littlo scales, which, with quartz, form more or less defined patches, and may be imagined to represent felspar-crystals. The bulk of the quartz occurs as an irregular mosaic traversed by subparallel rows of fluid-pores, which contain bubbles and sometimes minute crystals [1887].

On the crest of the slope the rocks have the same general character. Felspar is quite subordinate and sometimes wholly wanting, while the light mica is very plentiful. It occurs in relatively large flakes, in fan-liko, sheaf-like, or feathery groupings of smaller flakes, or in aggregates of minute scales, and is very pale to colourless in sections. Much of the rock exposed here has a porphyritic aspect, due to the development of large grains of quartz. In another type the quartz-mosaic becomes rather coarse-textured, the mica occurs only in rather large flakes, and the rock has more of the character of a true greisen. My friend Mr. L. J. Spencer, now of the British Museum (Natural History), has had the kindness to analyse this rock, and his results are given below, side by side with Mr. Hughes's analysis of the normal Skiddaw granite:—

	IV.	V.
SiO_2	75·223	80·36
Al_2O_3	11·140	11·12
Fe_2O_3	trace	1·77
FeO	1·771	
MgO	1·081	0·56
CaO	1·624	0·67
Na_2O	3·996	1·82
K_2O	4·516	2·47
Loss on ignition	0·500	1·96
P_2O_5	0·149	—
	100·000	100·73

IV. Skiddaw granite, White Gill (see Ward, Q. J. G. S. vol. xxxii. 1876, p. 5).
V. Greisen, eastern slope of Combe Height, 250 yards south of Grainsgill Lead-mine: sp. gr. 2·684.

As compared with the normal granite, the percentage of silica in the greisen shows an increase of about 5, while the figures for magnesia, lime, and the alkalies are about halved. Mr. Spencer's analysis shows that some of the mica must be of a soda-bearing variety, and most of the iron can be contained only in the same mineral, accounting for the yellowish tinge already mentioned.

Quartz-mica rocks with the same general characters as the above occupy the slope down to Grainsgill, and are seen in the beck and again in the lower part of Brandy Gill, encasing the lode which has there been mined for lead. In Grainsgill Beck similar rocks are seen eastward as far as the foot of Poddy Gill, where they are in contact with very highly metamorphosed Skiddaw Slates. Westward they extend about 250 yards above the junction with Brandy Gill, and re-appear in a small inlier in Grainsgill Beck about 150 yards farther. The rock here resembles that analysed.

On the hill-side south of Grainsgill the greisen is traversed by numerous veins of quartz and mica, from 1 inch to 1 foot in thickness, and some few of these also traverse the adjacent metamorphosed rocks. Quartz forms the bulk of each vein, the grey mica occurring sometimes in patches or pockets, sometimes in distinct seams, where the flakes are often grouped into rosette-like aggregates. Rarely the veins contain a few crystals of tourmaline: topaz and tinstone seem to be wholly absent.

14. Possible Cause of the Modification.

It will be seen from the foregoing account that these Cumbrian quartz-mica rocks differ in some respects from typical greisens, such as those of Cornwall and Saxony. On the other hand, they present some points of resemblance to the remarkable rocks in the Urals to which Gustav Rose gave the name beresite.[1] As described by Arzruni,[2] the latter consists essentially of white mica [3] and quartz, sometimes alone, sometimes with more or less orthoclase and plagioclase. The mica occurs in two habits, and is distinguished by Arzruni as primary and secondary. Other peculiarities of our rocks, such as the porphyritic quartz-grains and the quartzose veins, are also paralleled in the Russian rocks. The typical beresite, however, is richer in mica than the Grainsgill rocks: a non-felspathic example, from Beresowsk itself, yielded only 64·41 per cent. of silica, and was calculated to contain nearly 63 per cent. of mica. For this and other reasons I have preferred the name 'greisen' to that of 'beresite' for the rocks here described, while noting their difference from the better known type of greisen. In the beresites of the Urals, as in the rock of Grainsgill, topaz, tinstone, and other

[1] 'Reise nach dem Ural' (1837–42), vol. i. p. 186, vol. ii. p. 557.

[2] Zeitschr. Deutsch. geol. Gesellsch. vol. xxxvii. (1885) pp. 865–896. An earlier description by Karpinsky (1875–76), written in Russian and not very easily accessible, is summarized by Arzruni.

[3] This may include both muscovite and paragonite. In the only chemical analysis of the rock, by Karpinsky, the alkalies are not separately determined.

minerals characteristic of the true greisens are absent, and argentiferous galena is found. Arzruni gives a long list of other minerals from the mines of Beresowsk and neighbourhood,[1] only a few of which are known in our area. The beresite is the 'country' rock of the gold of the Urals.[2]

These Russian beresites form a system of broad bands, the relation of which to the normal granite of the district has not been clearly set forth. In the case of the Grainsgill rock the field-relations are scarcely open to question. The granite and the greisen form parts of a single intrusive body, and there is a transition, at first gradual, but ultimately more or less abrupt, from the former rock to the latter. The appearance is therefore as if the greisen had been 'extruded' from the granite, and a comparison is at once suggested with pegmatites such as those described by Mr. Barrow[3] in association with the igneous gneisses of Forfarshire and the neighbouring counties. Although these Highland rocks are richly felspathic, while the Cumberland greisen is almost free from felspar, a comparison of specimens brings out some curious points common to the two, such as the plumose arrangement of white mica which Mr. Barrow considers characteristic of his pegmatites. Again, the description of the Grainsgill rock given above has already suggested that the abundant minute flakes of mica may have been produced, in conjunction with quartz, by the destruction of felspar once present in the rock. The large flakes and plumose aggregates of mica, the porphyritic grains of quartz, and some other peculiarities which must date from the epoch of consolidation, preclude the supposition that the greisen is merely normal Skiddaw granite transformed by secondary metasomatic changes or by the agency of 'mineralizers' as a last phase of the igneous activity; but it is at least a tenable idea that the Grainsgill rock bears the same relation to a pegmatite of the Forfarshire type that the Cornish greisen does to its associated granite.

However this may be, it is significant to note, in another district, a greisen like that of Grainsgill and a pegmatite like those of Forfarshire occurring together and holding identical relations towards the granite, with which both are intimately connected During a recent visit to the Isle of Man, I had an opportunity, in company with my friend Mr. G. W. Lamplugh, of examining the granite of Foxdale. This rock, also intruded among Skiddaw Slates, is a muscovite-granite identical with some of the Leinster granites, on the axis of which it occurs. It consists of quartz, microcline, an acid plagioclase, muscovite, subordinate biotite, and little crystals of garnet and zircon. In the marginal part of the intrusion are developed bands and masses of pegmatite, thick veins and bands of

[1] See list by Kokscharow in Murchison's 'Geology of Russia,' vol. i. App. E (1845), pp. 640-645; also H. Louis, 'On the Mode of Occurrence of Gold,' Mineral. Mag. vol. x. (1893) pp. 241-247.

[2] See Murchison, De Verneuil, and Keyserling, 'Geology of Russia and the Ural Mountains,' vol. i. (1845) pp. 476, 477.

[3] Geol. Mag. 1892, pp. 64, 65; Quart. Journ. Geol. Soc. vol. xlix. (1893) pp. 330-337.

greisen, and finally quartz-veins containing only local aggregations of white mica or bordered by a narrow seam rich in that mineral. These quartz-veins, as at Grainsgill, traverse the other types of rocks.

Returning to the Cumbrian area, we note that the greisen occurs on the north side of an outcrop of granite, which is probably in subterranean continuity with the other outcrops to the south-west and south. In other words, it forms a fringe on the northern border of the large body of Skiddaw granite, though whether such fringe occurs on the northern edge only is a point on which we have no positive evidence. Regarding it as a modification of the granite, we see that, apart from subsequent chemical transformations, it must be due in the first place to some process of differentiation radically unlike any which have been discussed above. The cause of this differentiation was probably that advocated by Mr. Barrow in the case of his pegmatites, namely, mechanical force operating on the granite-magma when crystallization had already proceeded in it to a certain stage.

The Skiddaw granite, including the greisen,[1] has produced foliation on the cleavage-planes of the adjacent slates, and therefore belongs to the later group of igneous intrusions, to which also the other Lake District granites, those of Eskdale and Shap, must for various reasons be referred. From a general study of the district we are led to believe that all these intrusions, though in great part later than the cleavage, are intimately connected with the great post-Silurian crust-movements of which the cleavage-structure is only one manifestation. The forces by which these movements were produced were directed from south to north, and it is in this direction that the fringe of greisen- (or pegmatite-) magma seems to have been thrown out from the partially consolidated Skiddaw granite. If, when the zircon, the biotite, and part of the felspar had already crystallized, a portion of the still fluid 'mother-liquor' was squeezed out, it is clear that the partial magma thus forced northward would be of more acid composition than the granite as finally consolidated from the remainder, and would give rise by its crystallization to a rock of different type. How far the chemical difference between the granite and the greisen is thus accounted for, or how far that difference must be ascribed to subsequent chemical modification of the fringing rock, is a question not easily solved.

It may be remarked in passing that any connexion established between crust-movements and differentiation in rock-magmas must have a most important bearing on the problem of the geographical distribution of different types of igneous rocks in 'petrographical provinces' often divided by mountain-ranges.[2]

[1] The greisen seems to have given rise to more intense and widespread metamorphism than the granite. This extreme metamorphism produced by a very acid intrusion, rich in white mica, is in accord with what is known in other areas.

[2] See 'The Evolution of Igneous Rocks,' in 'Science Progress,' vol. i. (1894) pp. 152–165.

15. Conclusion.

In this and my former communication I have described, and to some extent discussed, some of the striking variations observable in the igneous rocks of the Carrock Fell district. While that area affords special facilities for such a study, it is probable that variations similar in kind, and perhaps in degree, occur among other well-known British rocks. The tendency to select in the field a 'typical' specimen, *i. e.* one similar to those already exhibited in museums or obtained by dealers from some particular quarry, has perhaps caused us to overlook or neglect in many cases the considerable variety of types met with in a single body of eruptive rock.

As regards the cause of the phenomena, enough has been said to show that many different considerations may legitimately enter into speculation on the subject. The most important kinds of variation described in the foregoing pages are:

(i) The increasing basicity of the gabbro from the centre to the margin of the intrusion, which is explained by a *concentration* of the basic elements in the cooler portion of the magma during the progress of crystallization.

(ii) The relatively basic modification of the granophyre at its junction with the gabbro, ascribed mainly to an *incorporation* of re-fused ultrabasic gabbro into the granophyre-magma.

(iii) The passage of the Skiddaw granite into a remarkable quartz-mica rock, which is perhaps a result of *mechanical pressure* operating on the granitic magma during its period of crystallization, but complicated by later metasomatic processes.

Some minor kinds of variation have also been noticed, and a study of the numerous dykes and veins, belonging to the latest phase of igneous activity at Carrock Fell, would doubtless bring out further points of interest.[1]

Nothing has been said of possible differentiation in igneous magmas prior to their intrusion, this being a matter of somewhat remote inference rather than a deduction from observation. It may be remarked, however, that all the results arrived at are consistent with the hypothesis that the gabbro and the granophyre were formed by magmas which were themselves partial magmas derived by differentiation from a common source. Such an idea is indeed suggested, not only by the close association of the two rocks, but also by their chemical composition. The similarity underlying their differences may be partly exhibited by a diagram analogous to those used by Iddings and others, in which the molecular proportions of silica and of the several bases are taken as abscissæ and ordinates respectively. I have preferred, however, to plot the atomic proportions of the corresponding elements, instead of the molecular proportions of the oxides; by this plan the several

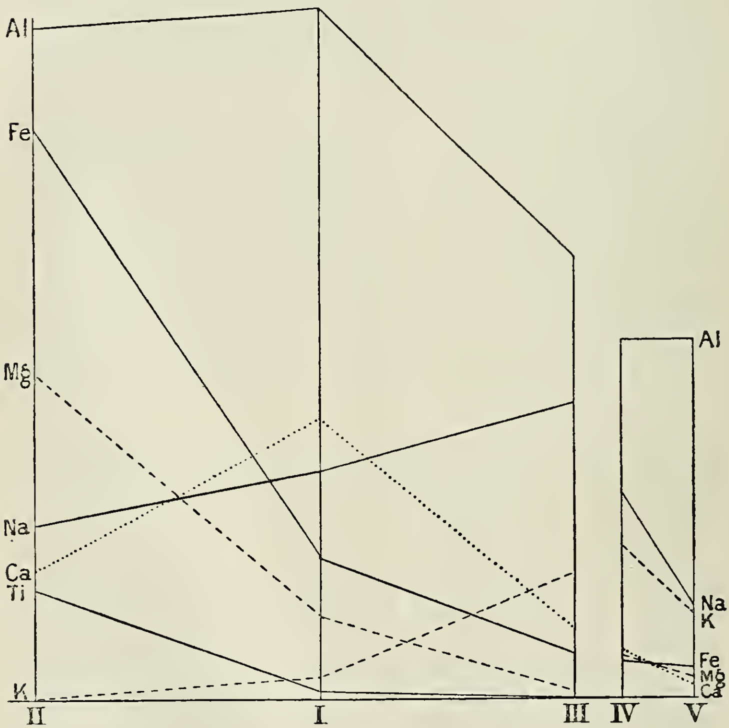
[1] See Geol. Mag. 1894, pp. 551–553.

curves are more distinctly separated, and the two iron oxides are united as metallic iron. The Roman numerals in the diagram refer to the chemical analyses given in the text, namely :—

II. Iron-ore gabbro.
I. Normal quartz-gabbro.
III. Granophyre.

The 'consanguinity' of the several rocks is thus clearly brought

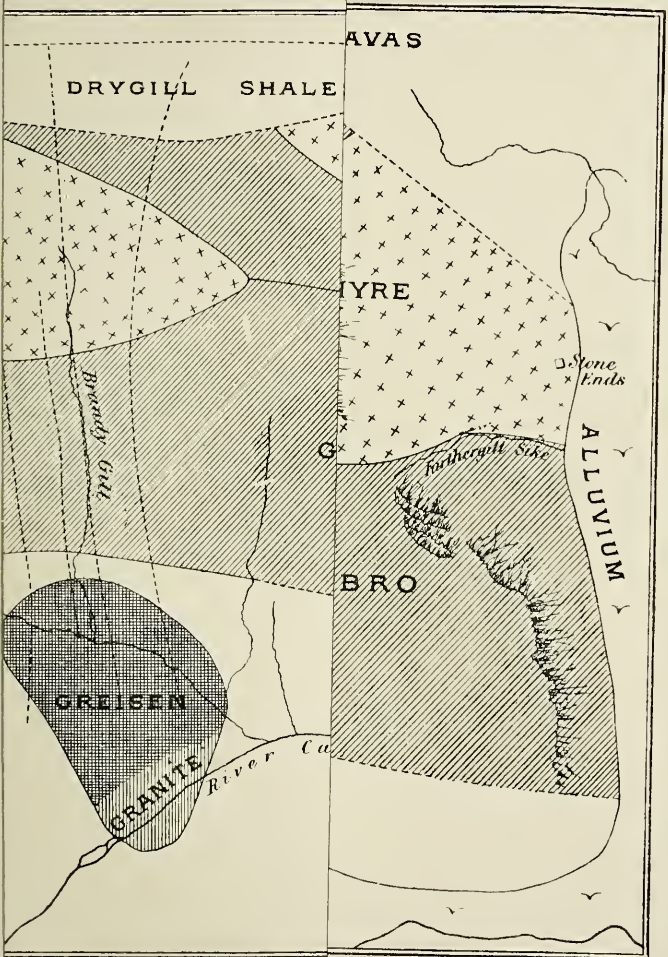
Fig. 3.—*Diagram showing the atomic ratios of the several constituents in the rocks of the Carrock Fell district.*

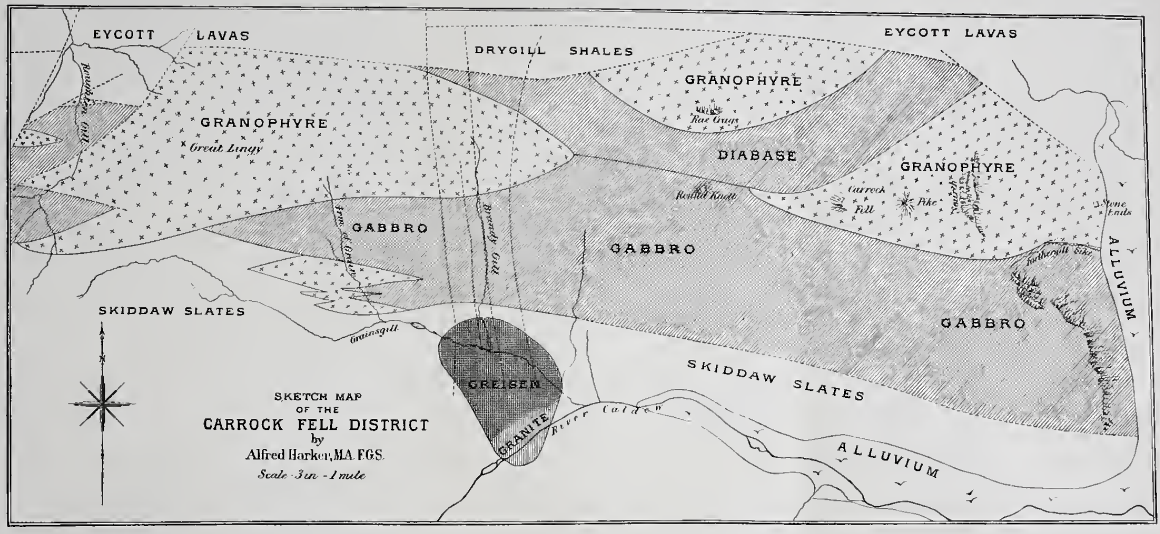


out. The Skiddaw granite, as already stated, probably belongs to a quite distinct group of intrusions. This also is illustrated by the diagram, which shows :—

IV. Skiddaw granite.
V. Grainsgill greisen.

The similarity of the greisen to the granite is apparent, but to bring them into connexion with the other group would require


AVAS
DRYGILL SHALE
YRE
G
BRO
Stone Ends
ALLUVIUM
Fothergill Sike
Brandy Gill
GREISEN
GRANITE
River Ca


EYCOTT LAVAS
DRYGILL SHALES
EYCOTT LAVAS
GRANOPHYRE
Great Lingy
GRANOPHYRE
Rae Crags
DIABASE
GRANOPHYRE
Carrock Fell
Pike
Round Knott
Stone Ends
GABBRO
GABBRO
GABBRO
Brandy Gill
ALLUVIUM
SKIDDAW SLATES
Grainsgill
GREISEN
GRANITE
River Caldew
SKIDDAW SLATES
ALLUVIUM
N
SKETCH MAP
OF THE
CARROCK FELL DISTRICT
by
Alfred Harker, M.A. F.G.S.
Scale 3 in - 1 mile

some rather unnatural zigzags, particularly in the aluminium- and magnesium-lines.

[Prof. Brögger has pointed out (Vidensk. Skr., math.-naturw. Klasse, 1894, no. 4, p. 196) a misconception underlying my statement in Quart. Journ. Geol. Soc. vol. l. p. 326, that the phenomena of differentiation described by him 'differ in a fundamental respect' from those of the Carrock Fell gabbro. He distinguishes two kinds of differentiation, *tief-magmatische* and *lakkolithische*; and the contrast which I drew should apply only to the former of these. The latter, or, as it is called in his paper on Gran, 'differentiation in the bosses,' is in no essential respect dissimilar to that described by me at Carrock Fell.—January 25th, 1895.]

EXPLANATION OF PLATE IV.

Sketch-map of the Carrock Fell district (scale: 3 inches = 1 mile), showing the distribution of the gabbro and diabase and of the granophyre; also the greisen of Grainsgill. The Skiddaw Slates, the Eycott Lavas (part of the Volcanic Series), and the Drygill Shales (belonging to the Coniston Limestone Group) are left blank.

The boundaries, especially in the western portion, where exposures are few, are often in part conjectural. The broken lines indicate faults.

Discussion.

Sir Archibald Geikie, complimenting the Author upon the skill with which he had worked out his subject, remarked that the summary of the paper, as expounded at the Meeting, was so condensed that criticism was hardly possible until the full paper was in print. There were only two points on which he would ask for further information. In the first place he wished that the Author would state whether he had any evidence of the date of the gabbro and granophyre-protrusions of Carrock Fell: they were admittedly much younger than the granite and greisen of Skiddaw. In the second place, he asked whether, among the various structures of the granophyre described by Mr. Harker, there was any distribution with reference to position in the body of the rock, and in particular whether any distinctive structures were observable in the marginal portion of the granophyre where it impinged upon the gabbro, which it had partly incorporated into itself.

Mr. Teall said that he had paid a short visit to the district some time ago, and had come away with the impression that there were transitions from gabbro to granophyre. The Author's more detailed observations proved that he (the speaker) must have been mistaken. He fully agreed with the Author as to the intimate relation between micropegmatitic and spherulitic structures. He considered that the microfelsitic spherulites of Rosenbusch were submicroscopic intergrowths of quartz and felspar. The greisen of Grainsgill appeared to be essentially distinct from that of St. Michael's Mount, Cornwall. The latter contained topaz, and was clearly due to an alteration of

the granite by vaporous exhalations or solutions acting outwards from ordinary joint-planes.

Prof. J. W. JUDD, Mr. J. E. MARR, Mr. GEORGE BARROW, and Mr. W. W. WATTS also spoke.

The AUTHOR thanked the speakers for their reception of his paper, and briefly replied to some of the questions raised. As regards the age of the gabbro and granophyre, he had not been able to come to any precise conclusion, but stratigraphical considerations indicated that these rocks were intruded subsequently to the post-Silurian crust-movements. The granite and greisen belonged to the epoch of those crust-movements. The granophyre showed structural as well as mineralogical modifications in the neighbourhood of the gabbro, assuming in places a singularly coarse texture. The rock which he had termed 'greisen' certainly differed from the rocks so named in Cornwall, and, in particular, it carried none of the special minerals so characteristic of the latter.